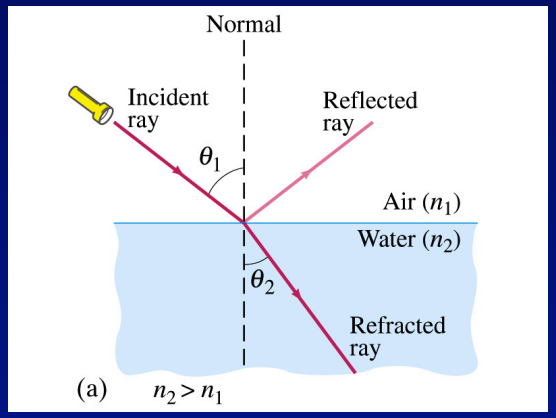
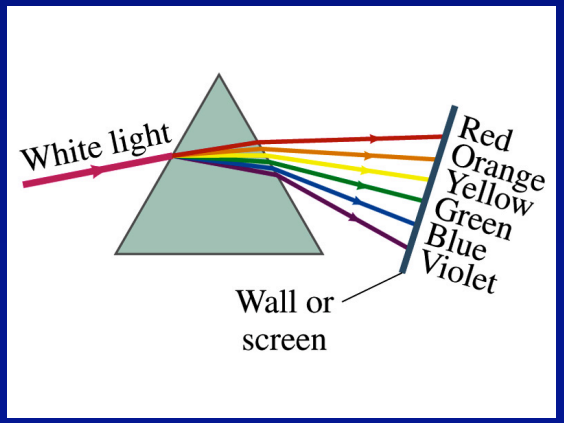
Chapter 33
The Nature and Propagation of Light

- Light rays
- Reflection
- Refraction
  - Index of refraction
  - Snell's Law
- Total Internal Reflection
  - Critical angle

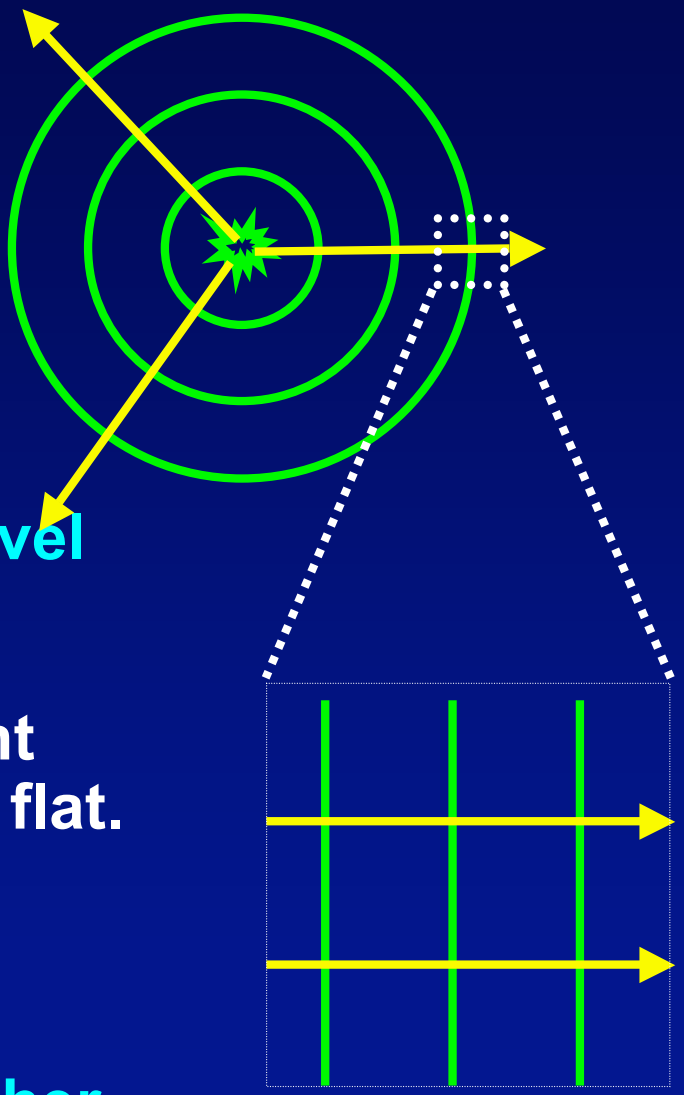




Light Rays

A point source of light emits spherical waves in all directions.

Each circle represents a wave front or crest of a wave.



Rays are:

- perpendicular to wave fronts
- point in the direction of wave travel
- are straight lines

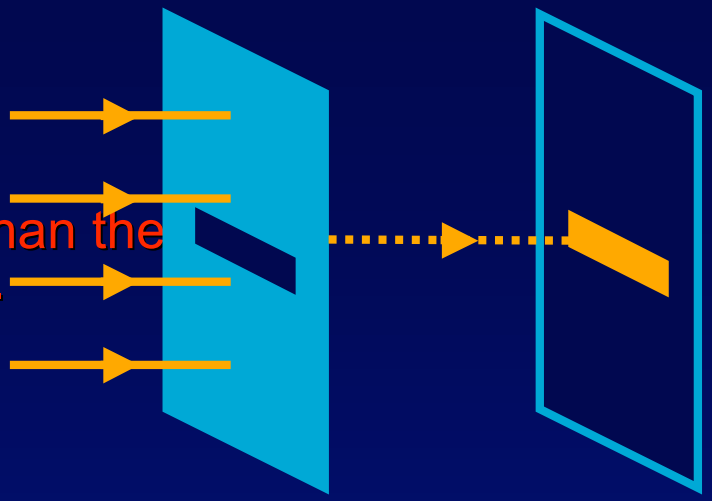
If we are far enough away from the light source, the spherical wave front looks flat.

$\Rightarrow$ plane waves

Note that for plane waves:

- wave fronts are parallel to each other
- rays are parallel to each other and $\perp$ to wave fronts

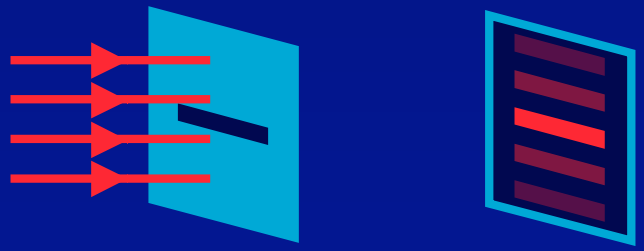
Geometrical Optics



- Assumption: the dimensions are much larger than the wavelength of the light waves (400 to 700 nm).
  - light follows straight-line paths (rays)
- Changes occur when a ray hits a boundary
  - ray may bounce off (reflection)
  - ray may bend into the other medium (refraction)
  - ray may be absorbed (light energy $\Rightarrow$ thermal energy)

Physical Optics

- Assumption: the dimensions are comparable to the wavelength of the light waves.
  - light must be considered as waves
- Waves exhibit
  - interference
  - diffraction

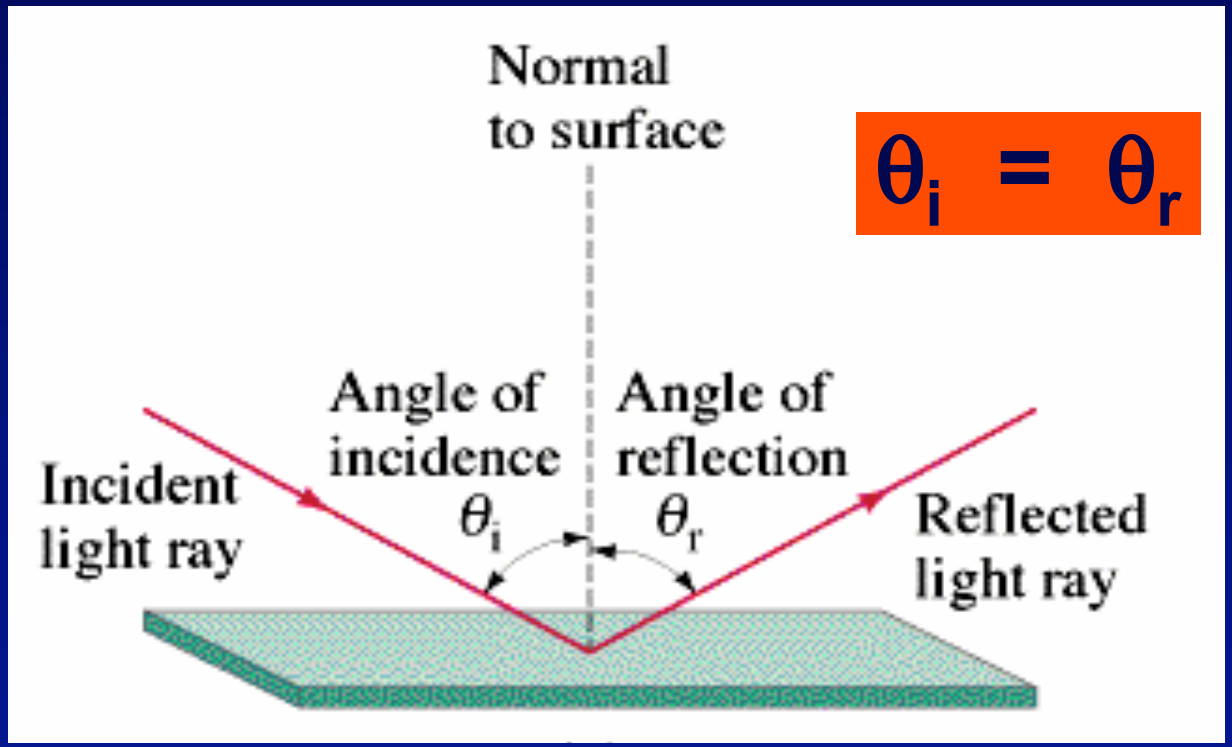


Reflection

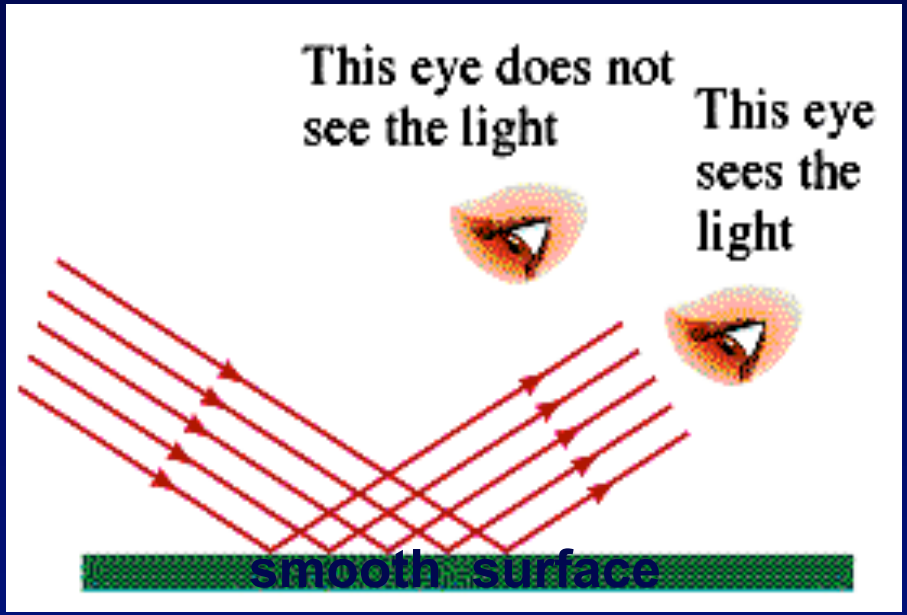
New Topic

Reflection

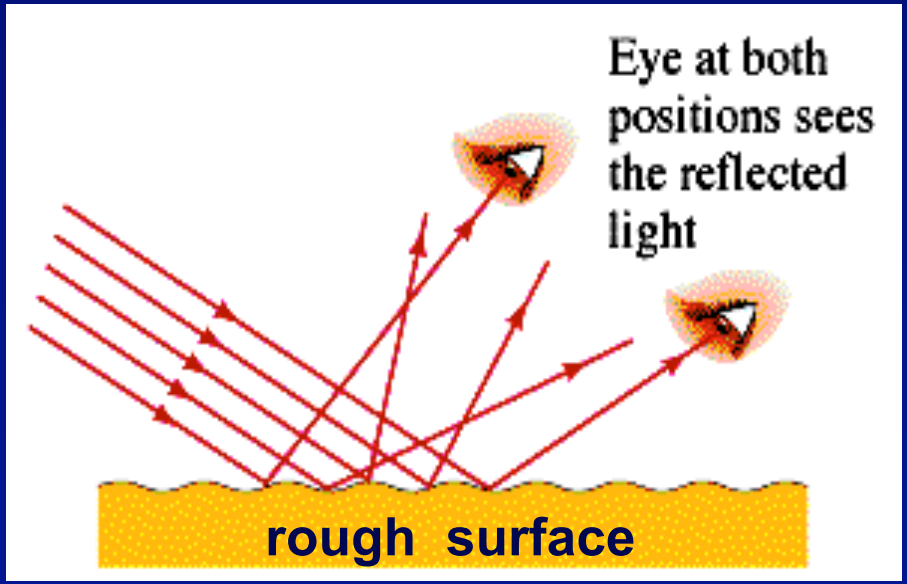
Angle of incidence = Angle of reflection



Notice the angles are measured with respect to the normal!



Specular reflection: **smooth** surface has only one good angle for reflected light to enter your eye



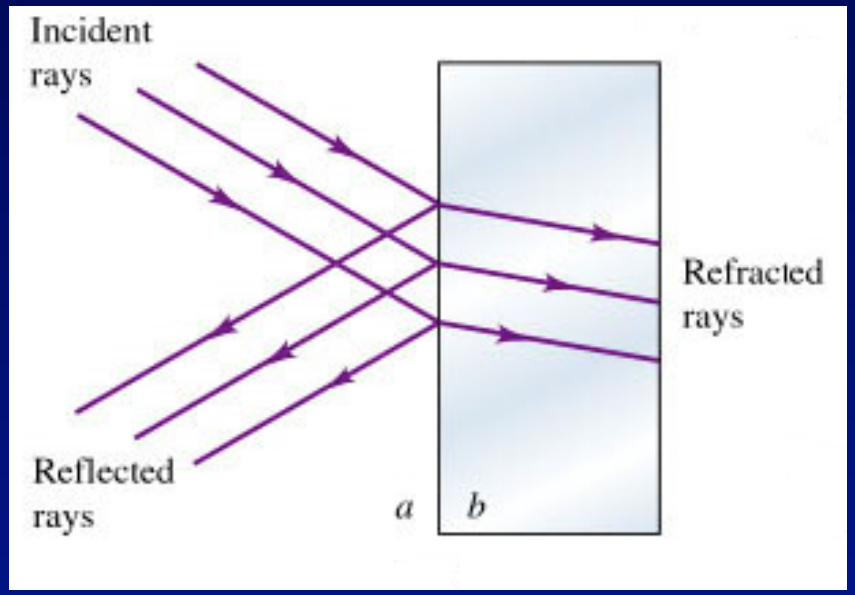
Diffuse reflection: **rough** surface has many different "angles" so reflected light can be seen at a variety of locations

Refraction

New Topic

Refraction of Light

What happens when light goes through a boundary?



It bends!

medium	n
vacuum	1.0
air	~1.0
water	1.3
glass	1.5
Diamond	2.4

Why ? ⇒⇒ light travels *slower* in a medium than in air:

- **index of refraction:** $n = c / v$

c = speed in vacuum

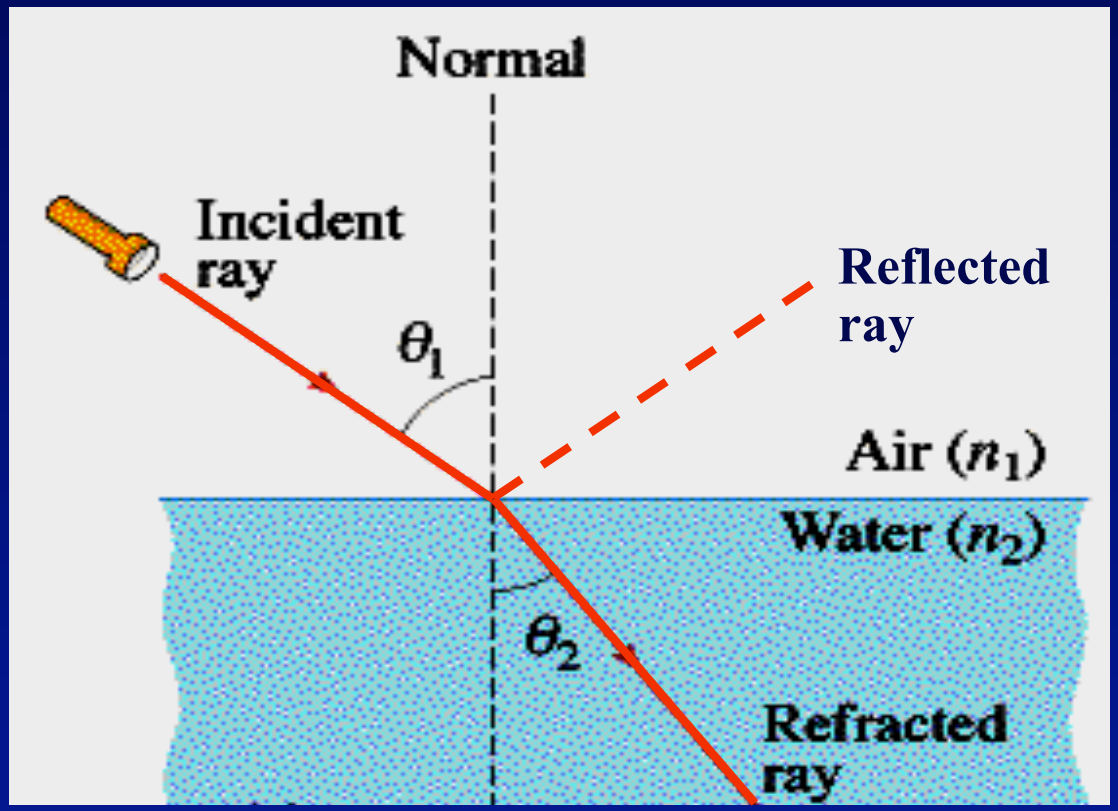
v = speed in medium

Refraction of Light

Snell's Law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

W. Snell (1591-1626)



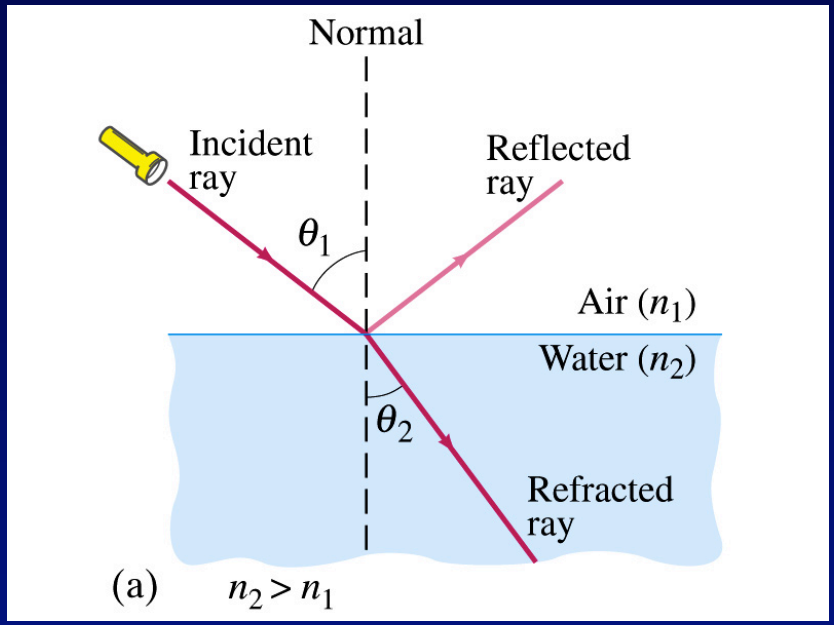
Note: the angles are defined relative to the normal.

Refraction: how does it bend?

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

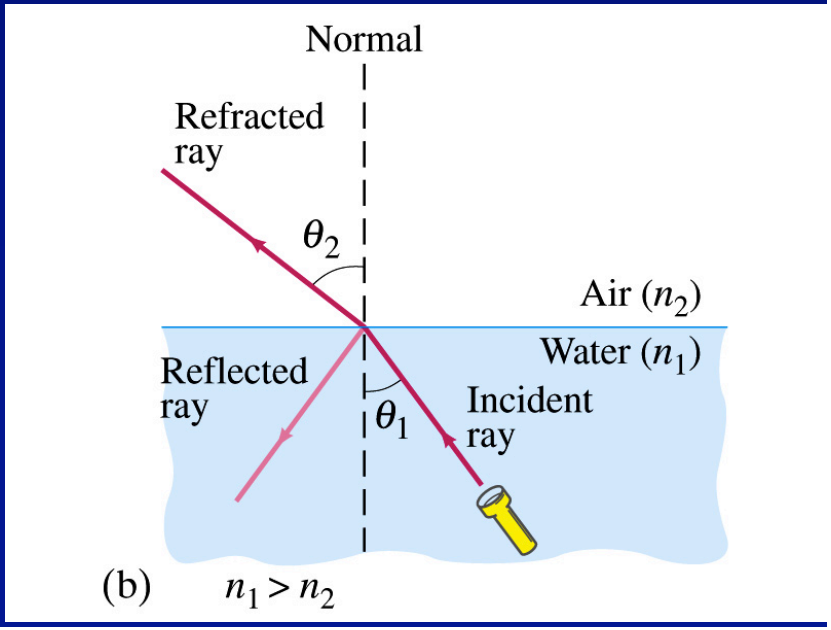
$$n = c/v$$

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{n_1}{n_2} = \frac{v_2}{v_1}$$



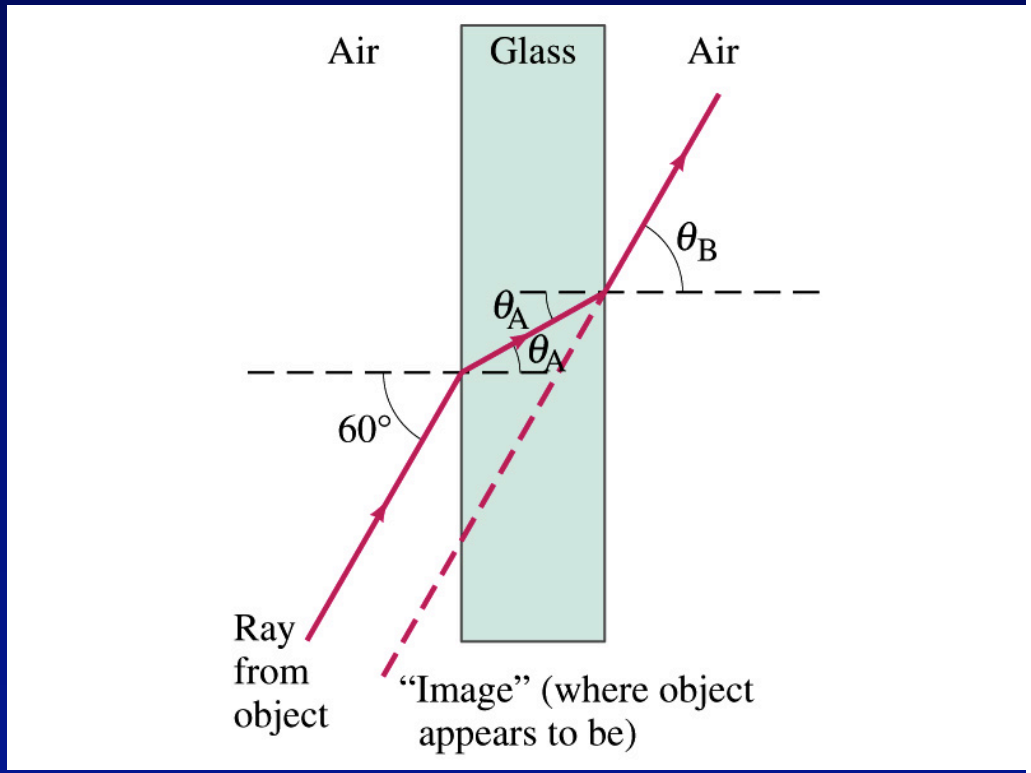
So if $n_2 > n_1$ (or $v_2 < v_1$), then $\theta_2 < \theta_1$, bend *towards the normal* !

So if $n_2 < n_1$ (or $v_2 > v_1$), then $\theta_2 > \theta_1$, bend *away from the normal* !



More on Refraction

- Consider a light ray which traverses a thick slab
  - ray bends *towards the normal* upon entering the glass
  - ray bends *away from the normal* when it exits from the glass
  - exiting light ray is at *same angle* as original ray, but is *shifted* over to one side



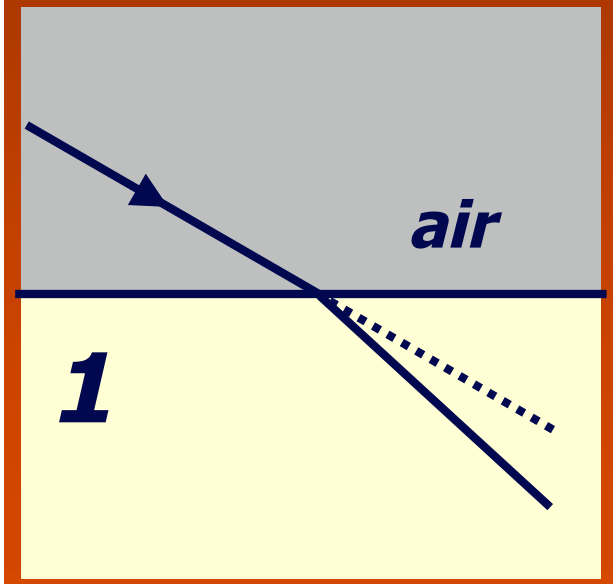
ConcepTest 33.1 Refraction

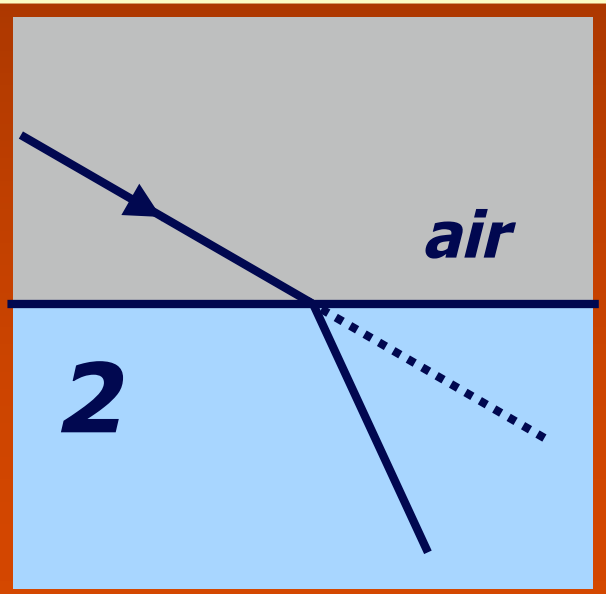
- Parallel light rays cross interfaces from air into two different media, 1 and 2, as shown in the figures below. In which of the media is the light traveling faster?

(1) medium 1

(2) medium 2

(3) both the same





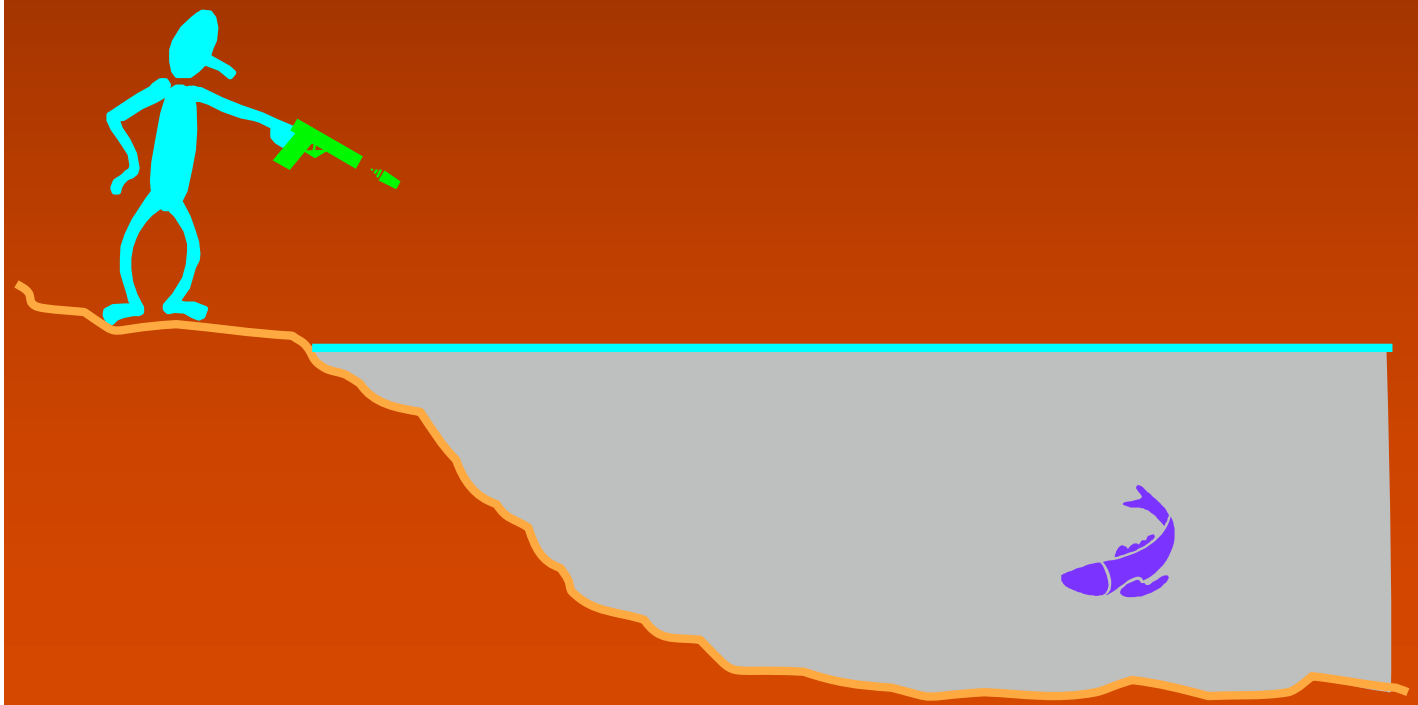
ConcepTest 33.2 Refraction

- To shoot a fish with a machine gun, what should you do?

(1) aim directly at the image

(2) aim slightly above

(3) aim slightly below



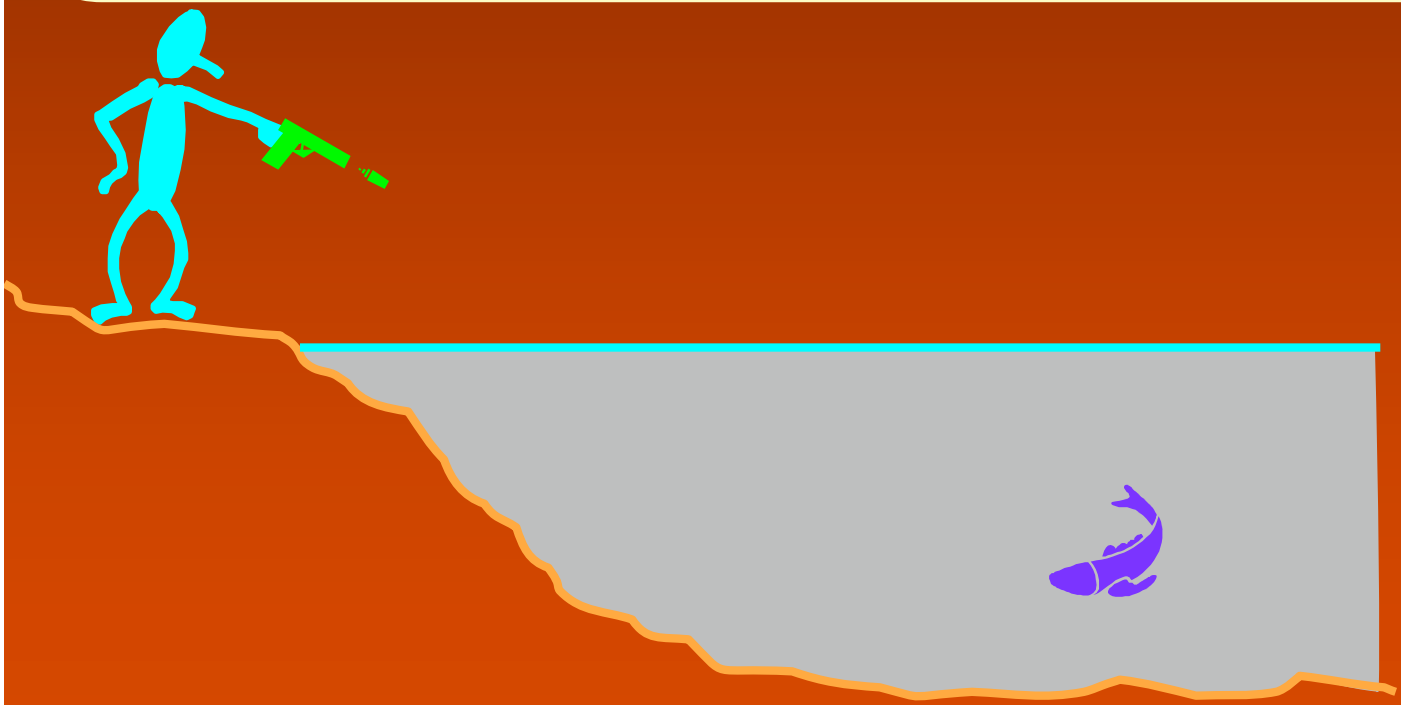
ConcepTest 33.3 Refraction

- To shoot a fish with a *laser gun*, should you aim directly at the image, slightly above, or slightly below?

(1) aim directly at the image

(2) aim slightly above

(3) aim slightly below

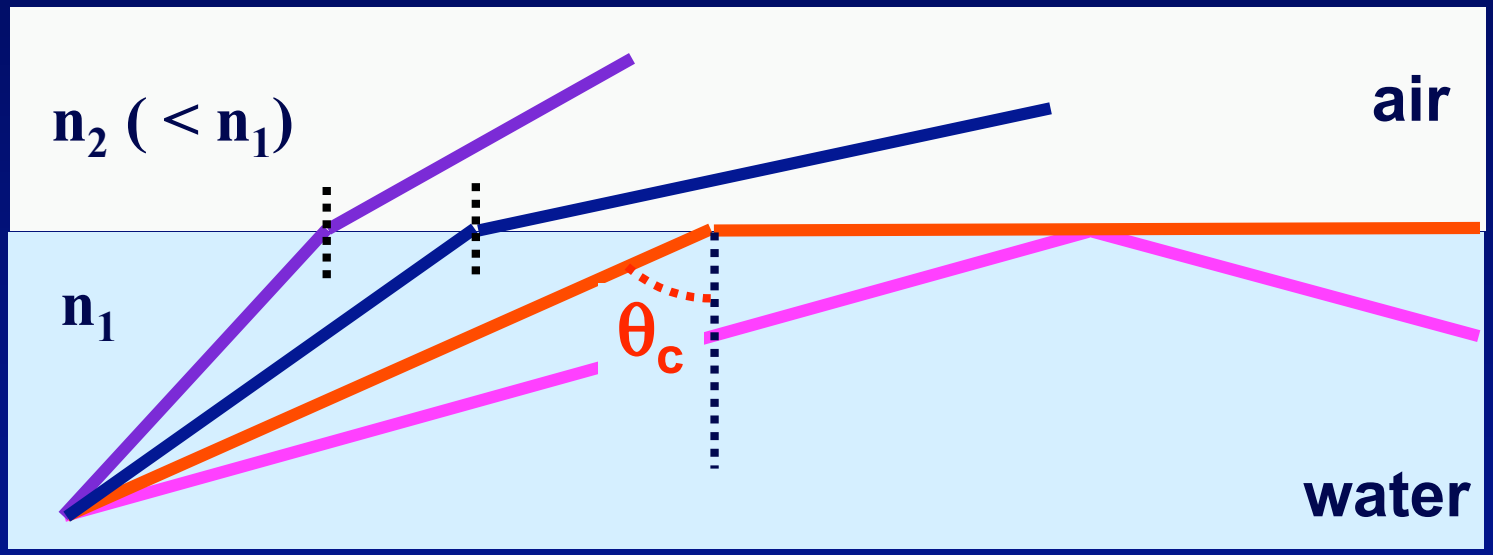


Total Internal Reflection

New Topic

Total Internal Reflection

- When light goes from a medium with high n into a medium with low n, rays bend away from the normal.
- At a particular incident angle (critical angle θ_c), the refracted angle becomes exactly 90°.

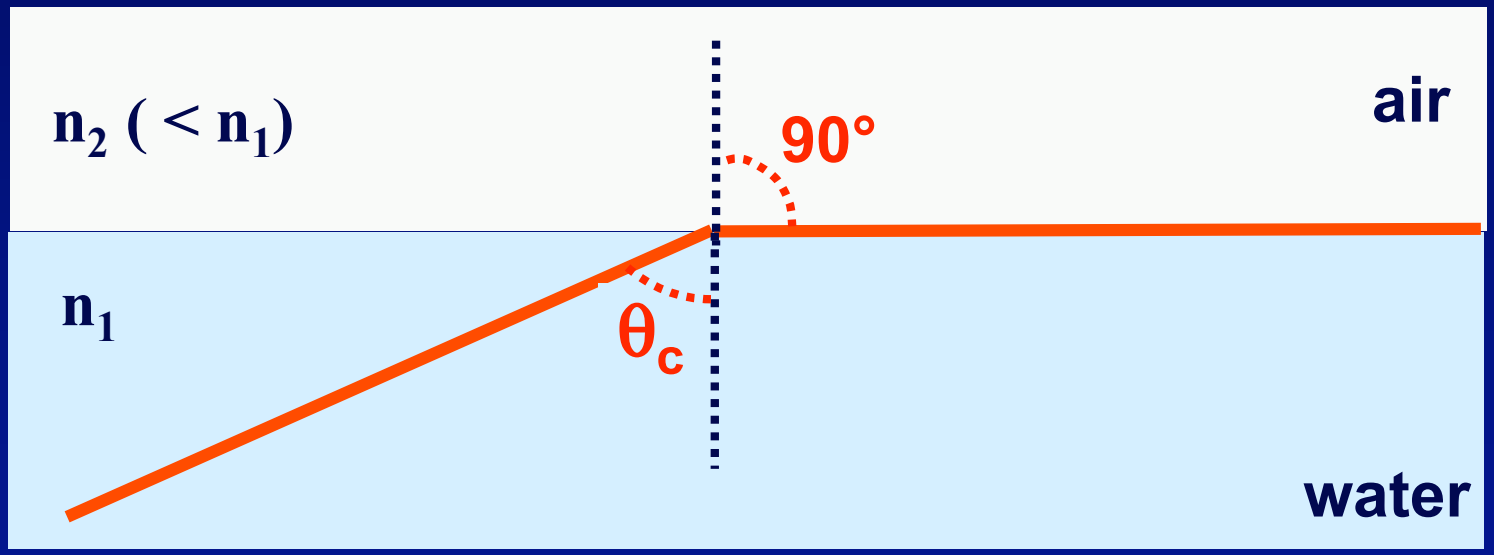


- At angles greater than θ_c there is no refracted ray at all. The incident rays are completely reflected !
  - this is *total internal reflection*

Total Internal Reflection

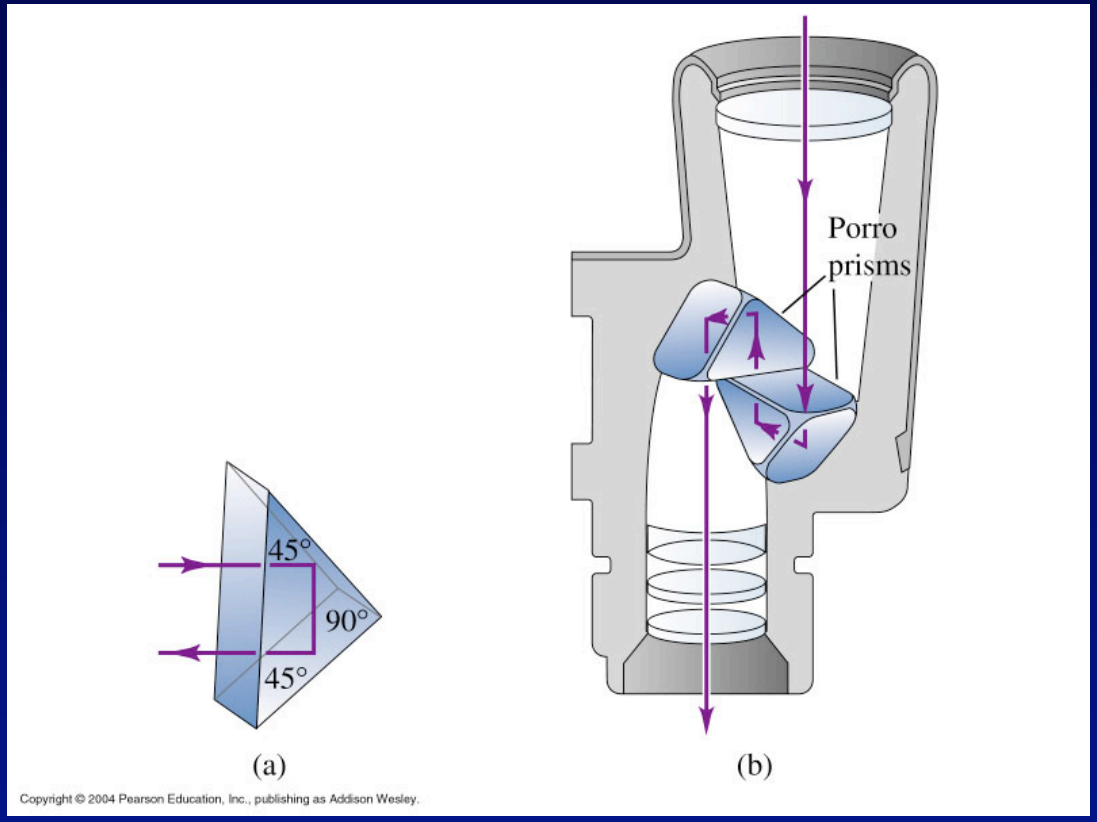
- What is the condition for total internal reflection?
  - when $\theta_i = \theta_c \longrightarrow$ refracted angle is 90°

$$n_1 \sin\theta_c = n_2 \sin 90^\circ = n_2 \quad \Rightarrow \quad \sin\theta_c = n_2 / n_1$$



- Remember: this only works when the *incident medium* has the *higher index of refraction*.

Example: binoculars use 45° prisms to reflect light

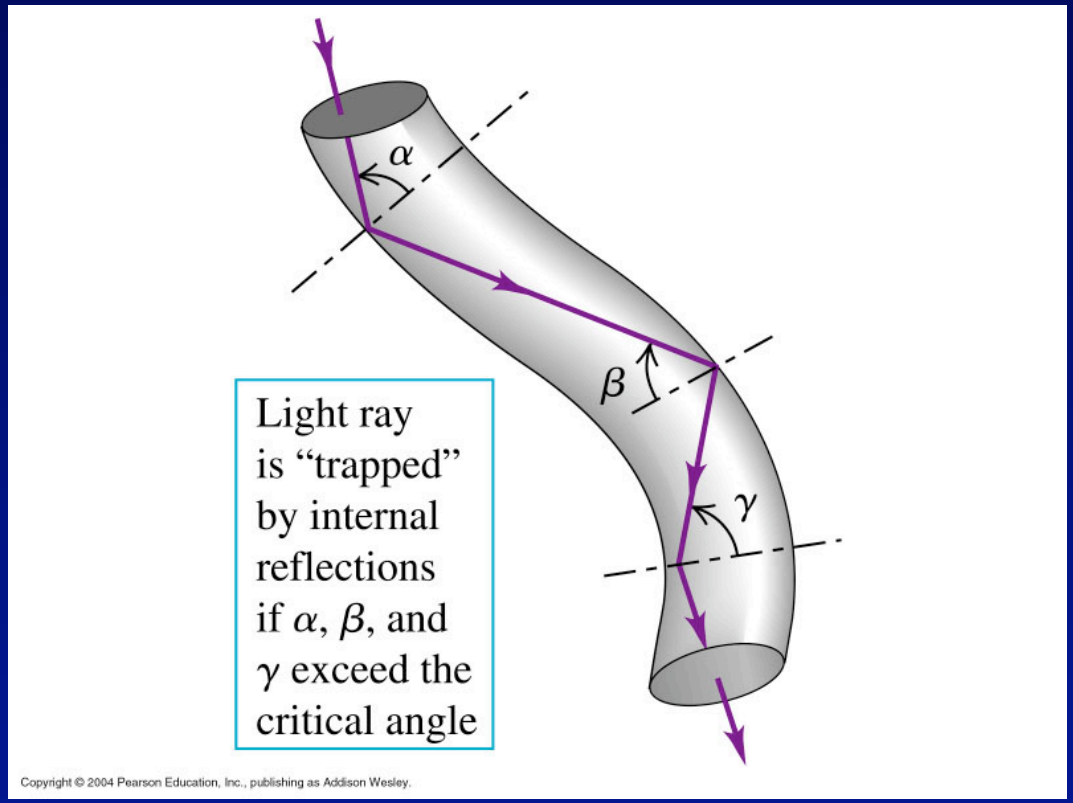


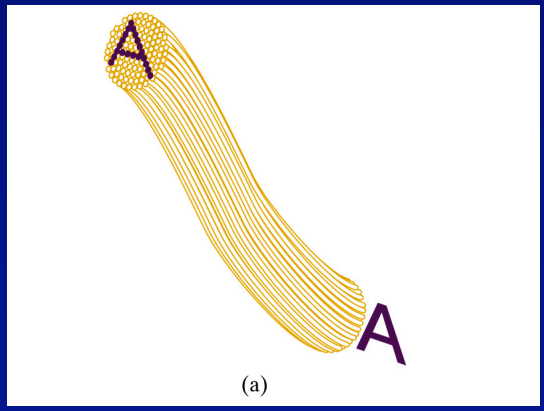
For glass with $n = 1.5$ we find that:

$\sin\theta_c = 1.0 / 1.5 = 0.67 \Rightarrow \theta_c = 41.8°$

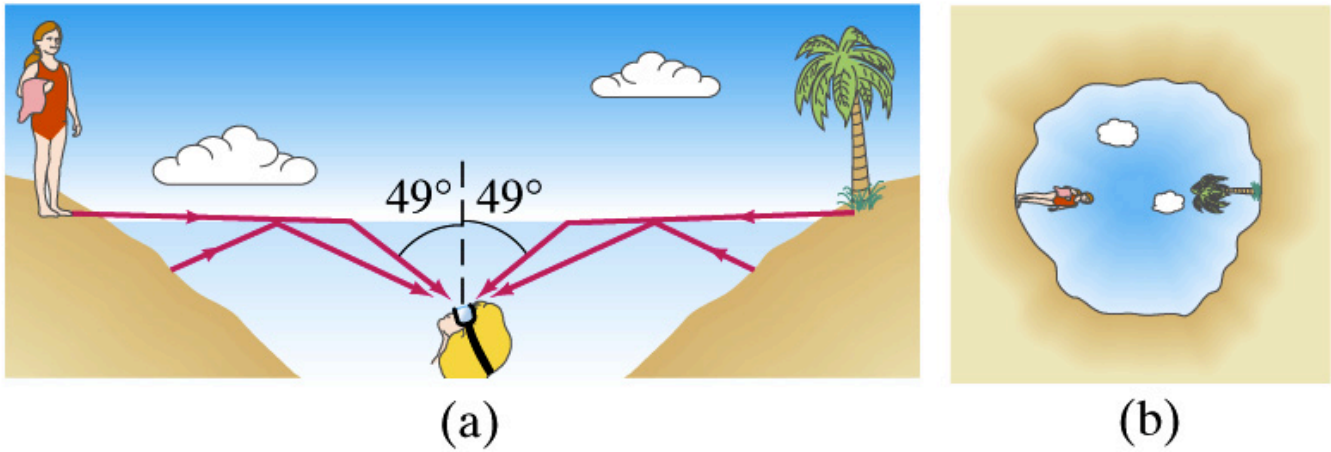
so for $\theta_i = 45°$, the light is totally reflected

Total Internal Reflection





The view from under the water



ConcepTest 33.4 Refraction

Light passes from a medium of index of refraction n_a into a second medium of index of refraction n_b. In order for total internal reflection to occur, it must be true that

1) $n_a > n_b$ and the incident angle θ_a is greater than the critical angle
2) $n_a > n_b$ and the incident angle θ_a is less than the critical angle
3) $n_a < n_b$ and the incident angle θ_a is greater than the critical angle
4) $n_a < n_b$ and the incident angle θ_a is less than the critical angle